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(56) Documents Cited
"Proc. of 1993 IEEE Intl. Conference on Neural Networks", 19 93, IEEE, New York, pp1123-8, Vol.2.
"Tenth UK Teletraffic Symp. Performance Eng. in Telecommunic ations Network" 1993,IEE, London, pp2/1-6.

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(54) Traffic routing in a telecommunications network

(57) A telecommunications network comprising a plurality of nodes interconnected via communications paths is configured by the determination of a routing plan for the traffic carried by the network. A set of possible paths, e.g. the eight shortest paths between each pair of network nodes is determined, and each path is allocated a digital code characteristic of that path identity. Groups of paths are selected, each group comprising one path from each set, and for each said group being characterised by a bit string comprising the digital codes of the paths comprising that group. These bit strings are then used as starting values or chromosomes in a genetic algorithm search procedure to generate and evaluate new path groups so as to determine an optimum combination or routing plan of paths between the network nodes.

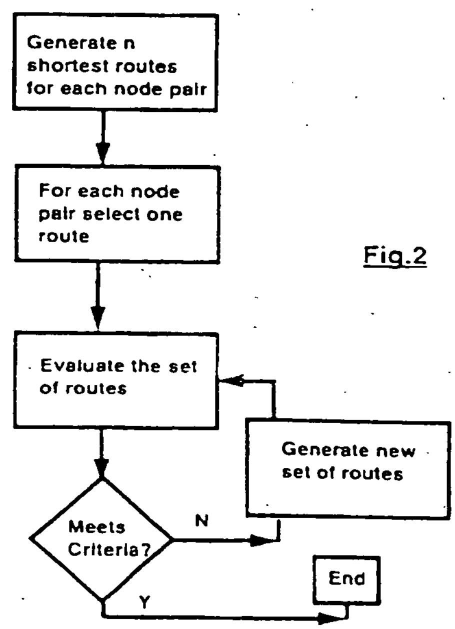

Fig.2

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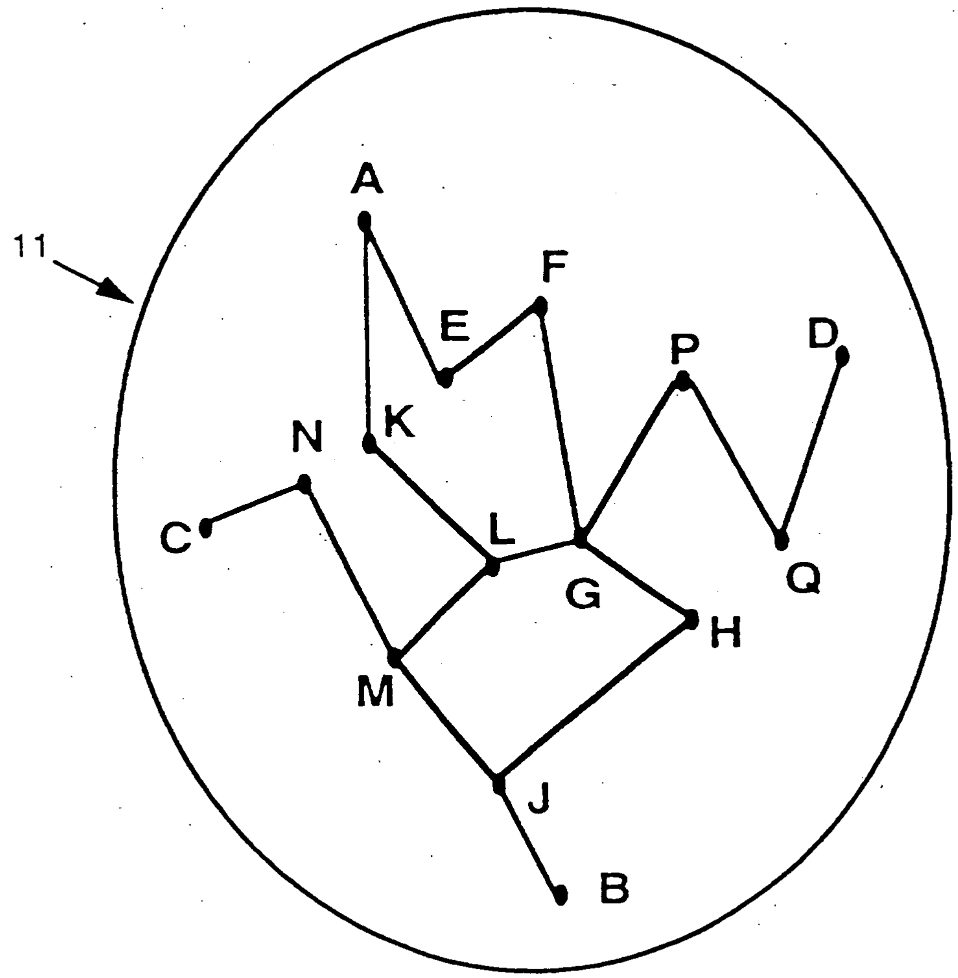

Fig.1

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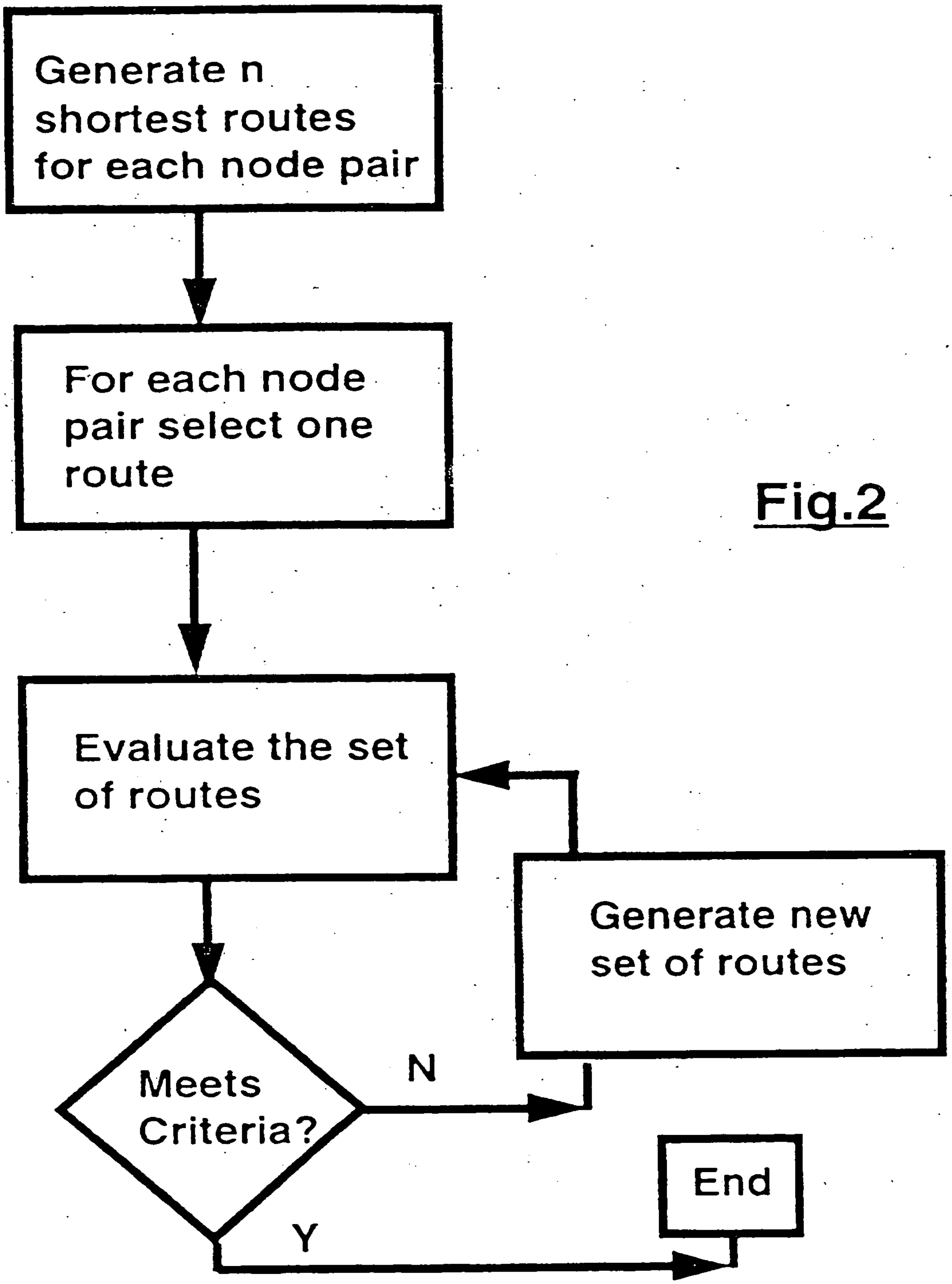

Generate n shortest routes for each node pair
For each node pair select one route
Evaluate the set of routes
Generate new set of routes
Meets Criteria?
N
Y
End

Fig.2

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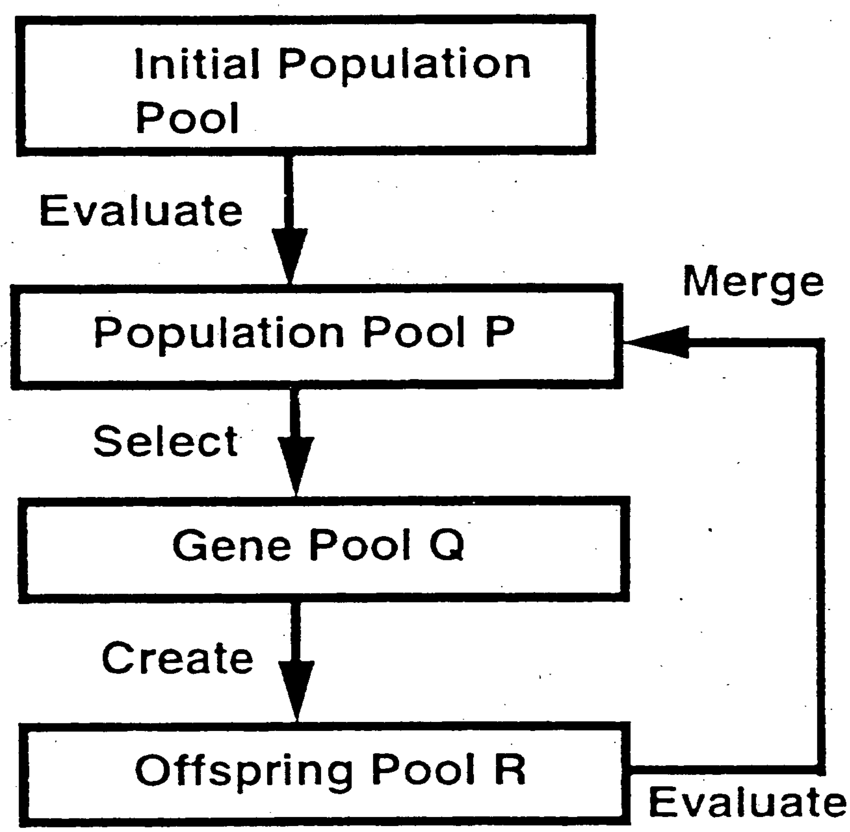
Initial Population Pool
Evaluate
Population Pool P
Merge
Select
Gene Pool Q
Create
Offspring Pool R
Evaluate

Fig.3

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TRAFFIC ROUTING IN A TELECOMMUNICATIONS NETWORK

This invention relates to the routing of telecommunications traffic in a network comprising a plurality of nodes interconnected by paths. In particular, the invention relates to a method of defining a traffic routing plan for such a network and to a method of routing traffic via the routing plan.

As telecommunications networks become more complex and the traffic load increases there is a need to determine the routing of traffic within a network so as to minimise the number of communication channels used, to reduce the risk of being unable to handle traffic and to minimise the total cost to the system operator. At present, traffic routing is determined largely on an empirical basis as a full analysis of a complex network to obtain an analytical solution is an intractable problem. It is thus very difficult if not impossible for an operator to ensure that a network is used with a high degree of efficiency under all traffic conditions.

The object of the present invention is to minimise or to overcome this disadvantage.

According to the invention there is provided a method of configuring a telecommunications network whereby to determine traffic routing, said network comprising a plurality of nodes interconnected by communications paths, and each said path incorporating one or more communications channels, wherein the method includes determining a set of possible paths between each pair of network nodes, allocating to each path of each said set a binary code characteristic of that path identity, selecting groups of paths each said group comprising one path from each set, composing for each said group a corresponding bit string comprising the binary codes of the paths comprising that group, and using the bit strings of said groups as starting values or chromosomes in a genetic algorithm search procedure whereby to generate and evaluate new path groups so as to determine an optimum combination of paths between the network nodes.

In another aspect, the invention provides a method of routing traffic in a telecommunications network comprising a plurality of nodes interconnected by communications paths, each said path incorporating one or more communications channels, wherein the method includes determining a set of possible paths between each pair of network nodes, allocating to each path of each said set a digital code characteristic of that path identity, selecting groups of paths each said group comprising one path from each set, providing for each said group a respective bit string comprising the digital codes of the paths comprising that group, and using the bit strings of said groups as starting values or chromosomes in a genetic algorithm search procedure whereby to generate and evaluate new path groups so as to determine an optimum combination of paths between the network nodes, and routing the traffic via said optimum combination of paths.

The genetic algorithm uses the bit strings representing the paths as chromosomes to generate new combinations of paths which are then evaluated to determine those which represent better solutions to the routing problem. The bit strings of these new paths then form new starting values in an iterative procedure which may be continued either until a solution satisfies predetermined criteria or until a predetermined number of iterative cycles have been completed.

A general description of the genetic algorithm procedure is given by J. H. Holland in 'Adaptation in Natural and Artificial Systems', University of Michigan Press, Ann Arbor, MI.

An embodiment of the invention will now be described with reference to the accompanying drawings in which;

Figure 1 is a schematic diagram of a typical network illustrating the routing of traffic between nodes;

Figure 2 is a flow chart illustrating the process of evaluating combinations of traffic routes;

Figure 3 illustrates the genetic algorithm procedure for determining routing solutions for the network of figure 1.

Referring to figure 1, there is depicted a highly schematic diagram of a telecommunications network 11 comprising a number of nodes A to Q, each adjacent pair of nodes in the network being coupled via a corresponding link. Traffic between a pair of nodes, e.g. A and B, is routed over a path which comprises one or more links. For example, traffic between nodes A and B may be routed over a path comprising the links between the nodes K, L, M and J, or over a path via the nodes E, F, G, H and J. In general there will be a large number of possible paths between a pair of nodes. In the network of figure 1, each link may conveniently be identified by its end nodes. Thus, the link between the nodes K and L is represented as KL. It will be appreciated that in the network of figure 1, there may be some links whose traffic handling capacity is higher than that of other links.

The choice of a particular route between a pair of nodes will in general depend on considerations of the bandwidth required to accommodate the traffic and the cost of the path to the network operator. However, this choice cannot be made in isolation as the traffic route between every other pair of system nodes must also be considered. Thus, in the network of figure 1, traffic between nodes C and D may be routed along a path via nodes N, M, L, G, P and Q. However, this particular route uses the link LM which is already used by one of the routes from A to B. If too many routes in the final routing plan for the network also use this particular link there may well be insufficient bandwidth on that link to accommodate the routing plan. It will also be appreciated that in the network of figure 1, each individual link will have a designated bandwidth. In the European SDH standard format this bandwidth may be represented in the form 1x63, 4x63 or 16x63, these being the number of virtual containers that are accommodated on a STM1, a STM4 or a STM16 path respectively. Thus, when considering usage of a particular network link, the bandwidth or capacity of that link must be taken into account.

It will be understood that when the routing of traffic between every pair of network nodes is considered, the problem of defining an optimum routing plan becomes extremely complex. A generally preferred solution to be aimed at is one in which every system link is used to 50% of its capacity, although in practice an acceptable solution is one which approaches this preferred solution.

Referring now to figure 2, this comprises a flow chart illustrating our method of determining an effective routing plan for the telecommunications network of figure 1. For every pair of nodes in the network we determine a set of n routes or paths between those nodes. Preferably, these paths comprise the n shortest routes between the two nodes. Conveniently n is a power of 2 and for most applications a set of 8 shortest routes may conveniently be employed. Each of these routes is identified by a three bit binary code which, in the case of 8 routes, will range from 000 to 111. The next step is to form groups of paths, each group comprising paths selected one from each set. Each group is represented as a unique bit string or chain formed from the binary codes of the paths forming the group. Thus for example, the bit string 010100110....... represents the group comprising the third path between the first pair of nodes, the fifth path between the second pair of nodes, the seventh path between the third pair of nodes and so on.

The groups of paths thus determined represent each a possible solution to the network routing problem, although some of these possible solutions may of course be infeasible e.g. on the grounds of cost and/or of traffic handling capability. These possible solutions are evaluated to determine a measure of their effectiveness as solutions.

The first part of the evaluation process assigns a cost, i.e. a network operator cost, to each bit string in the bit chain representing a path comprising one or more links. This cost is made up of the sum of the costs of the respective network links used by the traffic between the corresponding nodes. These costs, which may be stored in a lookup table, are summed to provide a path cost term (**C**) in a fitness function for the network.

In addition to the path cost, we also consider the total utilisation of each link in a proposed path group. For each group of paths we construct a utilisation matrix or table which identifies the total traffic demand imposed on every network link by those paths of the group which incorporate that link. I.e. for each path in that group we record a tally of the links used by that path. This tally will of course identify links whose capacity would be

overused or underused, and for each potential solution we determine the number (**B**) of links whose bandwidth capability would either be exceeded or would exceed a predetermined level of usage. This is in effect a congestion factor.

The evaluation process next determines the number of channels that will be required to support the traffic requirements. The amount of traffic on any link determines the number of channels (**N**) used. Finally, we include a penalty term to penalise the use of those links for which the proposed traffic exceeds the bandwidth capability.

We then define a fitness function **F** for each potential solution as:-

$$\mathbf{F} = w_1 x\mathbf{C} + w_2 x\mathbf{N} + w_3 x\mathbf{B}$$

Where w_1, w_2 and w_3 are weighting factors which the operator can define to force the process to concentrate on minimising either the path costs or the number of channels used, or to provide a trade off between these constraints. Appropriate values of these weighting factors will be determined by the system operator to match the particular network configuration and traffic requirements. The purpose of the genetic algorithm procedure is to generate new solutions or path groups whose fitness function is minimised.

Referring now to figure 3, this illustrates the genetic algorithm process for determining routing information from the potential solutions represented by the groups of paths. Each potential solution or path group can be regarded as a chromosome and the component bit codes representing the component paths of the group can be considered as the genes of that chromosome. The paths to be employed as the initial inputs to the genetic algorithm procedure may either be determined on a random basis or a preferred set of paths may be determined from their fitness function as defined above so that the most unfavourable paths are excluded from the initial selection.

The algorithm thus commences with an essentially random population of chromosomes, each chromosome representing a possible solution to the routing problem. Some of these chromosomes are selected by the

algorithm on the basis of their fitness function defined above to form a gene pool **Q** from which a new set or offspring pool **R** of chromosomes is created using a genetic operator. A new population pool **P'** is then constructed from the original pool **P**, the gene pool **Q** and the offspring pool **R**. This process is continued either until a solution is found which satisfies a predetermined criterion determined from the fitness function or until a particular time period has elapsed after which it is expected that little further improvement will result. It will be appreciated that the solution obtained in this manner may or may not be the best possible analytic solution to the routing problem, but it will at worst be a close approximation thereto. In formal terms, the algorithm may be listed as follows:-

GA
{objective is to minimise *value* (p) such that $p \in U$}
P, **Q**, **R**: multiset of solutions $\subset U$;
initialise (**P**)
while not *finish* (**P**) **do**
    begin
    Q := *select* (**P**);
    R := *create* (**Q**);
    P := *merge* (**P**,**Q**,**R**)
    end
end GA

In each iteration the algorithm manipulates the genes in the gene pool to generate new path combinations which are then evaluated for fitness. By selecting the better potential solutions this establishes a gene pool containing the more favourable genes.

Having determined an appropriate solution to the problem in the form of a binary bit string, this solution is then translated back into path routing information for application to the network.

In a further application, the technique may be employed as a design tool for the modification or extension of an existing network e.g. to accommodate increased traffic demand. Such modification will generally include the addition of further nodes to the network and/or an increase in the channel capacity of one or more network links.

CLAIMS

1. A method of configuring a telecommunications network whereby to determine traffic routing, said network comprising a plurality of nodes interconnected by communications paths, and each said path incorporating one or more communications channels, wherein the method includes determining a set of possible paths between each pair of network nodes, allocating to each path of each said set a digital code characteristic of that path identity, selecting groups of paths each said group comprising one path from each set, providing for each said group a respective bit string comprising the digital codes of the paths comprising that group, and using the bit strings of said groups as starting values or chromosomes in a genetic algorithm search procedure whereby to generate and evaluate new path groups so as to determine an optimum combination of paths between the network nodes.

2. A method as claimed in claim 1, wherein said evaluation comprises determining for each said new path group a fitness function based on the total cost, the total number of communication channels used and the traffic congestion associated with that path.

3. A method as claimed in claim 2, wherein the components of the fitness function are individually weighted

4. A method as claimed in any one of claims 1 to 3, wherein each said set of paths comprises the shortest routes between the respective nodes.

5. A method as claimed in any one of claims 1 to 4, wherein the number of paths in each said set is a power of two.

6. A method as claimed in claim 5, wherein each said set of paths comprises eight paths.

7. A method of configuring a telecommunications network substantially as described herein with reference to and as shown in the accompanying drawings.

8. A telecommunications network configured by a method as claimed in any one of the preceding claims.

9. A method of routing traffic in a telecommunications network comprising a plurality of nodes interconnected by communications paths, each said path incorporating one or more communications channels, wherein the method includes determining a set of possible paths between each pair of network nodes, allocating to each path of each said set a digital code characteristic of that path identity, selecting groups of paths each said group comprising one path from each set, providing for each said group a respective bit string comprising the digital codes of the paths comprising that group, and using the bit strings of said groups as starting values or chromosomes in a genetic algorithm search procedure whereby to generate and evaluate new path groups so as to determine an optimum combination of paths between the network nodes, and routing the traffic via said optimum combination of paths.

10. A method of routing traffic in a telecommunications network substantially as described herein with reference to and as shown in the accompanying drawings.

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Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

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	Date of completion of Search 28 JUNE 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: INSPEC; WPI	Documents considered relevant following a search in respect of Claims :- 1 TO 10

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
X	"Proc of 1993 IEEE Intl. Conf. on Neural Networks", 1993, IEEE, New York, pages 1123-8, Vol. 2 (N SHIMAMOTO ET AL) "A dynamic routing control based on a genetic algorithm".	1, 9 at least
A	"Tenth UK Teletraffic Symposium. Performance Engineering in Telecommunications Network", 1993, IEE London, pages 2/1-6. (M C SINCLAIR) "The application of a genetic algorithm to trunk network routing optimisation", especially Sections 5, 5.1, 5.2	1, 9

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